**Title: SWITCHING REGULATOR, STEP-DOWN TRANSFORMER IN PARTICULAR, AND SWITCHING REGULATION METHOD**   **Matter: 3901**   **Client: 10191**   **Application No: 10/517742**
**(P41388 USW 0 30297)**

# SWITCHING REGULATOR, STEP-DOWN TRANSFORMER IN PARTICULAR, AND SWITCHING REGULATION METHOD

Background Information

The present invention relates to a switching regulator, a step-down transformer in particular, and a switching regulation method.

5 Switching regulators (SR), such as buck converters or step-down converters, are used in many applications, for voltage matching and voltage reduction in particular, in switched-mode power supplies, for example.

In direct voltage supply circuits (power supply units) voltage is generally regulated by
10 switching regulators via a timing voltage which is applied to the control terminal of a power transistor. In the simplest case, a timing frequency is derived by the regulator from the direct voltage (controlled variable) to be regulated according to the deviation from the reference variable (system deviation) and this timing frequency times the power transistor and thus provides the regulated output direct voltage, after low-pass filtering in particular.

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The open loop gain of a switching regulator results essentially from a gain $v_R$ of a control amplifier, gain $V_{PWM}$ of a pulse-width modulator (PWM), ratio kist of an actual voltage divider of the output voltage in the feedback path, and the gain or damping $H_{TPLC}$ of an LC low-pass filter at the output of a power amplifier of the switching regulator: ($V$ = kactual x $v_R$
20 x $V_{PWM}$ x $H_{TPLC}$).

Gain factor $V_{PWM}$ of the pulse-width modulator results from the quotient between a battery voltage $U_{BAT}$ (input signal) and a delta voltage $U_{osc}$ which is supplied to the pulse-width modulator ($V_{PWM} = U_{BAT}/U_{osc}$), delta voltage $U_{osc}$ being 1.25 $V_{SS}$, for example.

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Due to the great fluctuation range of battery voltage $U_{BAT}$, of approximately 6 V to 40 V, and possibly even 60 V, which must be taken into account, gain factor $V_{PWM}$ of pulse-width modulator (PWM) has a relatively large dynamic range. As a result, the total gain varies by a factor of 10 (20 dB) due to the battery voltage variation range alone, which may result in

stability problems of the overall control circuit, or in control and accuracy losses in the case of a reserve established on the basis of the maximum gain.

Changes in the battery voltage, in particular sudden changes, are identified and subsequently adjusted in the feedback path of the control circuit of a switching regulator only with a relatively long delay time, which results in dynamic harmonics in the output voltage. Relevant for the delay is the LC low-pass filter ($H_{TPLC}$) having a cut-off frequency $f_{gTP}$ of: $f_{gTP} = (1/2\pi) \times (1/(LC)^{0.5})$.

A typical method for circumventing the above-named problems is presented in M.R. BORGHI Smart Power ICs, Springer Verlag 1996. The amplitude of delta voltage $U_{osc}$ supplied to the pulse-width modulator is regulated as a function of the battery voltage $U_{osc} = f(U_{BAT})$, delta voltage $U_{osc}$ being in the range between 200 mV and 2 V, for example. One disadvantage in the case of relatively small amplitudes of delta voltage $U_{osc}$ in a timed system results due to the resolution inaccuracy, which is critical. In addition, amplitude feedforward compensation is relatively complicated to implement.

Another typical method for circumventing the above-described problems is a pre-distortion of delta voltage $U_{osc}$, the oscillator voltage supplied to the pulse-width modulator being only quasi-delta shaped, and a linear section in the area of the tip of the delta having an exponential area where no feedforward effect is achieved, since the oscillator does not change its voltage amplitude, in particular not as a function of battery voltage $U_{BAT}$, and thus no direct compensation regulation occurs (see also MULLER RS, KAMINS TI (1986) Devices For Electronics Integrated Circuit, John Wiley & Sons).

The object of the present invention is to provide a switching regulator, in particular having feedforward compensation, and also a switching regulation method having a gain which is essentially independent of an input signal.

Advantages of the Invention

This object is achieved according to the present invention by the switching regulator as recited in Claim 1 and the switching regulation method as recited in Claim 12.

The present invention is based on the fact that gain $v_R$ of a control amplifier is approximately proportional to the battery voltage.

The object of the present invention as recited in the preamble is achieved in particular by the fact that a compensation device controls gain factor $v_R$ as a function of an input voltage, in particular a fluctuating input voltage ($U_{BAT}$, for example), in such a way that the overall gain of the switching regulator remains essentially constant over battery voltage $U_{BAT}$.

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Advantageous refinements of and improvements on the respective objects of the main claims are presented in the subclaims.

According to an advantageous refinement, an amplifier device has a complex grounded

10 resistor, in particular for adjusting a primary gain and/or frequency compensation.

According to another preferred refinement, a filtering device has a low-pass filter, in particular having an inductance and a capacitance and a diode connected in parallel thereto.

According to another preferred embodiment, the oscillator signal supplied to the pulse-width

15 modulating device has a delta oscillator voltage.

According to another preferred refinement, a switching device has a transistor, a MOSFET in particular.

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Drawing
An exemplary embodiment of the present invention is depicted in the drawing and elucidated in detail in the description that follows.

25 Figure 1        shows the block diagram of a switching regulator, having feedforward
                 compensation in particular, to elucidate an embodiment according to the
                 present invention.

Description of the Exemplary Embodiments
30 Figure 1 shows the block diagram of a switching regulator, having feedforward compensation in particular, to elucidate an embodiment according to the present invention.
In Figure 1, an input signal 1, a battery voltage $U_{BAT}$ in particular, is supplied to a compensation device 2, a feedforward compensation module (FFK) in particular, which generates a compensation signal 3, a compensation current $I_{FFK}$ in particular, as a function of

35 the amplitude of input signal 1.

An amplifier device 7, a control amplifier $R_V$ or transconductance amplifier in particular, receives compensation signal 3 and modifies gain factor 6 $v_R$ of amplifier device 7 according to compensation signal 3. A complex resistor 8 is connected to amplifier device 7 and is essentially used for adjusting the primary gain of amplifier device 7 and/or the frequency

5   compensation. A reference signal 4, a reference voltage $U_{REF}$ in particular, and an actual value signal 5, an actual voltage $U_{actual}$ in particular, are also supplied to amplifier device 7 to generate an amplifier signal 23.

An oscillator signal 9, a delta oscillator voltage $U_{osc}$ in particular, having any desired,

10   essentially constant, amplitude is also supplied, as is amplifier signal 23, to a pulse-width modulating device 11, a pulse-width modulator (PWM) in particular, which generates a pulse-width modulated signal 22 amplified by a gain $v_{PWM}$, which is supplied to an additional amplifier device 12 having gain $v_p$. A switching signal 21 is generated in amplifier device 12, which is essentially used as a power adapter for actuating a switching device 13.

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Switching device 13, a MOSFET power amplifier in particular, switches through input signal 1 as a function of switching signal 21 to a filtering device 14 and as a result generates a pulsed signal 24, which is smoothed in filtering device 14, which has a low-pass filter in particular having a serial inductance 15 and a grounded capacitance 17 connected

20   downstream from inductance 15.

A freewheeling diode 16, which is used for protecting filtering device 14 against voltage surges, among other things, is connected to ground in parallel to filtering device 14. Pulsed signal 24 is smoothed in filtering device 14 to yield output signal 18, a voltage in particular,

25   which is supplied to amplifier device 7 (actual value signal 5) via a resistor network 19, a voltage divider 19 in particular having gain or division kist, and a feedback path 20.
Gain $v_R$ or transconductance $s_R$ of control amplifier 7 is corrected using battery voltage $U_{BAT}$ (input signal 1) in such a way that the product $v_1 = (U_{BAT}/U_{osc}) \times v_R$ remains constant over the battery voltage.

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Delta oscillator voltage $U_{osc}$ may be selected arbitrarily, e.g., $U_{osc} = 1.25$ V. The loop gain in the control circuit of a buck converter, which in first approximation is independent of the battery voltage according to the present invention, represents an implementation of a feedforward compensation, i.e., the control amplifier or pulse-width modulator responds to a

sudden change in the battery voltage immediately, without delay of the output-side low-pass filter.

The implementation of such a switching regulator using feedforward compensation is inexpensive and requires little space.

For gain $v_R$ of control amplifier RV, the following applies:

$v_R = Z \times [1/(R \times k \times U_{BAT})]$,

where Z represents the complex resistance of a selectable external resistor, having an ohmic and/or capacitive resistance in particular. The product of transconductance $S_R$ and complex resistance Z is also equal to gain $v_R$ of control amplifier RV, transconductance $S_R$ being compensation current $I_{FFK}$ divided by temperature voltage $U_T$, and compensation current $I_{FFK}$ being generatable from a ring-type current source and satisfying the equation

$I_{FFK} = U_c / (R \times k \times U_{BAT})$, R being the Tk0 resistance of the ring-type current source, and k being a factor for adjusting gain $v_R$. By combining the above equations and equation

$V_{PWM} = U_{BAT}/U_{osc}$, the product of the two gains $V_R$ and $V_{PWM} = v1$ becomes

$v1 = Z /(R \times k \times U_{osc})$, which in first approximation is independent of the battery voltage and in the event of battery voltage surges corrects the gain dynamically, without delay time of the output low-pass filter, so that harmonics in output voltage $V_{out}$ are prevented.

Although the present invention was described above with reference to a preferred exemplary embodiment, it is not limited thereto, but may be modified in many ways.

Although in the example above the compensation device emits a current signal for controlling the gain factor of the amplifier device, another signal form (voltage signal, optical signal, etc.) is also conceivable here or for the other mentioned signals. A different oscillator output signal form is also conceivable, as well as a modified filtering device or the omission of the additional amplifier device having gain factor $v_p$.

The present invention is also not limited to the above-mentioned applications.